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Optimal Merging of Point Sources Extracted from Spitzer Space Telescope Data in Multiple Infrared Passbands Versus Simple General Source Association

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Abstract. For collating point-source flux measurements derived from multiple infrared passbands of Spitzer-Space-Telescope data – e.g., channels 1-4 of the Infrared Array Camera (IRAC) and channels 1-3 of the Multiband Imaging Photometer for Spitzer (MIPS) – it is best to use the 'bandmerge' software developed at the Spitzer Science Center rather than the relatively simple method of general source association (GSA). The former method uses both source positions and positional uncertainties to form a chi-squared statistic that can be thresholded for optimal matching, while the latter method finds nearest neighbors across bands that fall within a user-specified radius of the primary source. Our assertion is supported by our study of completeness (C) vs. reliability (R) for the two methods, which involved MIPS-24/IRAC-1 matches in the SWIRE Chandra Deep Field South. Both methods can achieve $C = 98\%$, but with $R = 92.7\%$ for GSA vs. $R = 97.4\%$ for bandmerge. With almost a factor of three lower in *unreliability* $(1 - R)$, bandmerge is the clear winner of this comparison.

1. Introduction

At the Spitzer Science Center (SSC), we have developed a number of software tools for merging point sources extracted from multiple-wavelength Spitzer-Space-Telescope image data. Generally, the tools are stand-alone software programs, which we call 'modules', that can be executed from the command line and have well defined inputs and outputs. Included are tools for re-adjusting the point-source positions and positional uncertainties, so that a second iteration of merging will yield improved results (Laher and Fowler 2006). There are also utilities to estimate the upper limit of the flux density for detections that are absent from certain bands, to estimate the performance of the merging, and more. The modules have been built for all four major platforms (Solaris, Linux, Mac, and Windows), and are available on the Spitzer website.

The purpose of this paper is to utilize the performance-estimation modules and compare the performance of two different methods of merging point sources from different spectral passbands: bandmerge and general source association (GSA). After describing the two methods briefly in the next section, we compare completeness (C) and reliability (R) performance curves for the two methods based on our Monte Carlo simulations. We also discuss the reason why the optimal method works much better than the simple method, and under what conditions similar performance between the two methods can be expected.

2. The Two Merging Methods

The SSC 'bandmerge' module uses decision theory to perform optimal merging of point sources from up to seven different Spitzer bands (four IRAC channels and three MIPS channels). Input source positions and positional uncertainties are required in separate files for each band. This module is the centerpiece of the SSC bandmerge-GUI package[1] (This URL has documents that describe in more detail the methods briefly mentioned in this paper.).

The SSC 'gsa' and 'mgsa' modules perform general source association, i.e., point-source matching based only on positional proximity. The gsa program merges two point-source lists. The mgsa program iteratively executes the gsa program to merge three or more point-source lists. Only input azimuthal/elevation position coordinates are required (e.g., Right Ascension and Declination). This simple method is useful when positional uncertainties are unavailable. GSA is general and, therefore, not limited to Spitzer data.

3. Results and Discussion

We examined the case of merging IRAC-1 (3.6 μm) point sources with MIPS-24 (24 μm) point sources from the SWIRE data set; see Lonsdale *et al.* (2003) for a more complete description of the SWIRE data. Figure 1 presents our completeness vs. reliability results for the two methods. Figure 2 shows how these quantities vary with user-specifiable threshold, which is the dimensionless chi-square threshold in the case of bandmerge (left panel) and the search radius, in arcseconds, in the case of GSA (right panel).

Our Monte Carlo simulation employed 9,912 MIPS-24 detections that had real matches in IRAC-1 and 991 that did not (the real data appeared to have about this rate of detection in IRAC-1 of sources detected in MIPS-24) and 27,313 IRAC-1 detections with no MIPS-24 counterparts. These detection counts match the real SWIRE data. The 9,912 IRAC-1 detections that matched MIPS-24 detections were given positions drawn from a 2-D correlated Gaussian pseudorandom number generator based on the real MIPS-24 positions and uncertainties. The other IRAC-1 detections were uniformly distributed over the field, but with a few deleted that came closer to other IRAC-1 detections than the point-source extractor can produce, leaving the number quoted. At several threshold levels, three independent Monte Carlo simulations were run, resulting in negligible changes in bandmerge's superiority over GSA but fluctuations of about 0.1% in both C and R for both methods (1-σ).

Defining "unreliable" here as a MIPS-24 detection that had no real IRAC-1 partner, but matched an IRAC-1 detection that had no real MIPS-24 counterpart anyway (type 1), we find that the lower rate of unreliability for bandmerge relative to GSA is the biggest difference between the two methods (left panel of Figure 3). The other kind of unreliable match is the MIPS-24 detection that has an IRAC-1 partner, but gets matched to the wrong IRAC-1 detection (type 2); this occurs less frequently and is a weaker function of threshold (right panel of Figure 3). Both methods suffer about the same from type-2 mismatches.

[1] `http://ssc.spitzer.caltech.edu/postbcd/download-bandmerge.html`

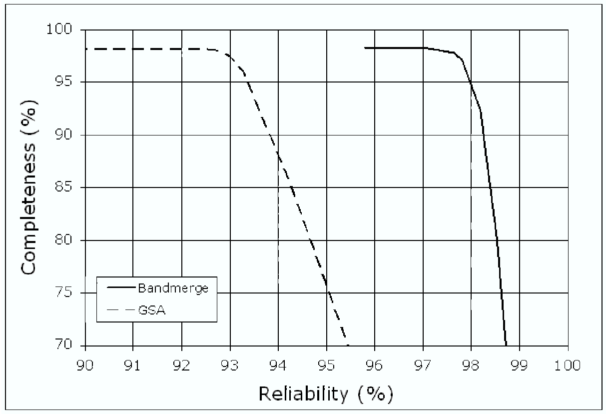

Figure 1. Completeness versus reliability for bandmerge and GSA.

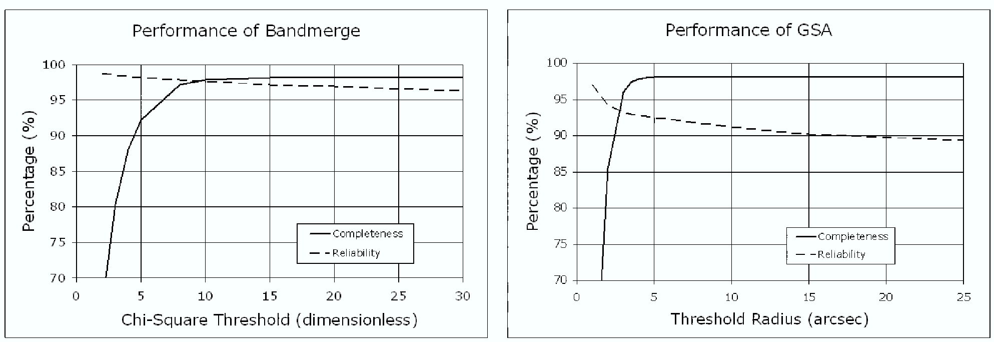

Figure 2. Completeness and reliability as a function of user-specifiable threshold: bandmerge (left) vs. GSA (right).

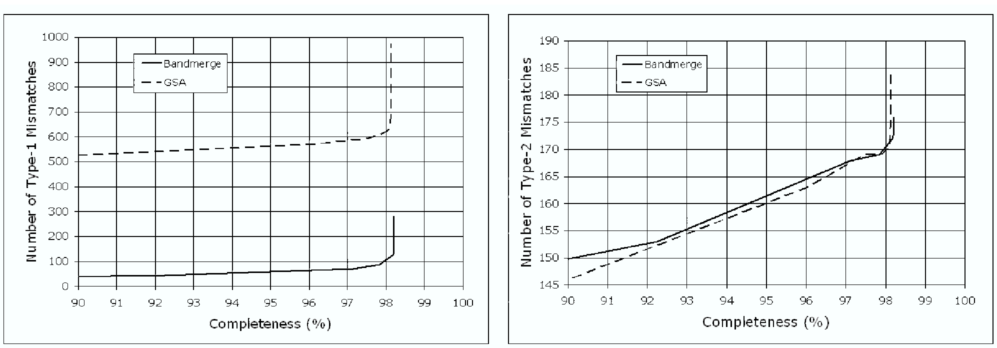

Figure 3. Number of type-1 (left) and type-2 (right) unreliable matches versus completeness for bandmerge and GSA.

Note that GSA is asymmetric with respect to whether IRAC-1 or MIPS-24 is given preference in taking its preferred match. This asymmetry results when GSA is run in the best-match-only mode, which it must be in this case, since retaining all matches that pass the test generates a plethora of unreliable sources. The "best-match" relationship itself is fundamentally asymmetric and can be handled only with more elaborate confusion-resolution logic such as bandmerge possesses. The effect of swapping detection-list roles on GSA is primarily confined to a small number of gains and losses of correct matches, with little fluctuation in C & R, whereas bandmerge is not affected at all.

Finally, we point out that bandmerge works especially well relative to GSA when the positional uncertainties are disparate among the point-source lists being merged. The same is true when the error elipse is rotated and/or has significant length differences between its major and minor axes. Conversely, the performance of bandmerge will be comparable to GSA if the point sources being merged all have identical, circular positional uncertainties (which is *not* the case for the data set we studied), although bandmerge will always be superior for merging more than two bands, because of its more complete confusion disentanglement logic.

4. Conclusions

These SWIRE data are photometrically deep and therefore somewhat predisposed to confusion. No automated merging method can perform at the level most scientists would like (typically $C = 98\%$ at $R = 99.8\%$), but bandmerge certainly comes a lot closer than GSA. Both methods can achieve $C = 98\%$, but with $R = 92.7\%$ for GSA vs. $R = 97.4\%$ for bandmerge. This translates into bandmerge having a reduction in *unreliability* $(1 - R)$ by almost a factor of 3 lower than GSA. High reliability or low unreliability is important because astronomers study objects with peculiar properties, which are likely to have false matches.

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